THE APPLICATION OF COMPUTER SIMULATION TECHNIQUES TO THE DESIGN AND PRESERVATION OF A NATIONAL MONUMENT

Edward Ng, Khee-Poh Lam, Wei Wu
School of Architecture, National University of Singapore, 4 Architecture Drive, Singapore 117592
Takehiko Nagakura
Department of Architecture, MIT, 77 Mass. Avenue, Cambridge MA 02139, USA

ABSTRACT

The paper outlines a two-year research program where Radiance was used in the conversion of Empress Place, a national monument in Singapore, into an Asian Civilisation Museum. The paper describes how the research team fine-tune the modeling and software settings to cope with some of the contextual issues of design. Inaddition, the paper discusses how Radiance could be used to aid the design of the building. One of the more difficult tasks the researchers faced was to model and validate some of the daylighting control devices that are part of the existing features of the building. And to design new control devices that are architecturally consistent with the building. Working with the design team, options and strategies are studied. At the end, contrary to the original beliefs of the architect, and much to the liking of the curator, it has been demonstrated that, carefully designed, daylighting could be introduced into the gallery and that it will enhance the quality of the interior spaces. The building is currently under construction.

BACKGROUND

The use of Computer Aided Design Techniques for lighting design attracts great interest from architects and lighting designers. A great number of software and tools are available.[1] Radiance is one of the examples. Radiance is a collection of programs for the graphical simulation and analysis of lighting. It uses the technique of backwards ray-tracing to calculate scene illuminance and has the ability to account accurately for both diffuse and specular inter-reflection in complex spaces.[2] Radiance is developed by the Lawrence Berkeley National Laboratory at Berkeley, USA.[3] The program is particularly suitable for the simulation of complex lighting environment and to cope with complicated architectural geometry.[4] And it has been applied successfully in the design of buildings.[5] [6]

However, most of the projects previously studied were conducted in an idealized situation with little external contextual restrains. Typically, in those studies, designers have a lot of freedom in controlling and changing the design variables. They include the immediate site conditions, orientation and geometry of the spaces, position and sizes of the openings, and the use of daylighting control devices.

The present research focuses on the use of Radiance in a real life situation. In this case the design and conversion of the Empress Place Building, a national monument in Singapore, into an Asian Civilisation Museum. Adding to the complexity of coping with the reality of a design problem, which will be explained later, is the fact that it is the first time Radiance is used to aid the design of buildings in a tropical environment.

The Empress Place Building (figures 1, 2, 3) is one of the more important buildings erected by the early British Administration which is still standing today. In 1995, the government decided to convert it into an Asian Civilisation Museum. The curator of the museum has been very keen to introduce daylighting into the gallery spaces and in 1996 requested the research team to conduct studies on one of the galleries in order to test the validity of his wishes.

After a preliminary survey of the building and noting some of the problems associated with the studies, the research team developed an 8-months work plan in consultation with the client and the architect. To limit the scope of work, only overcast sky conditions will be studied.

Figure 1 Empress Place Building

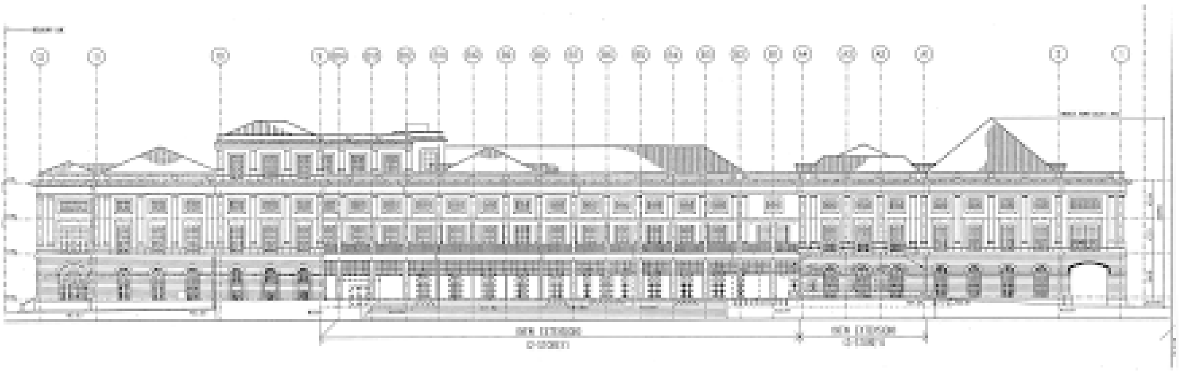

Figure 2 Elevation of Empress Place Building

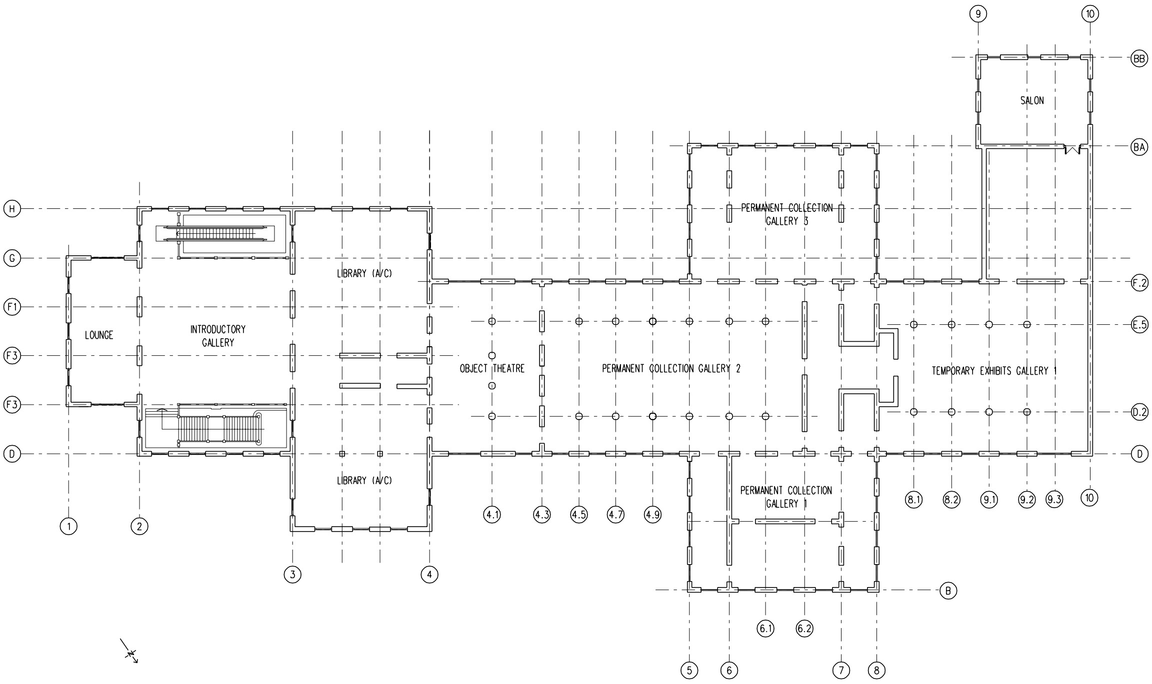

Figure 3 The main gallery floor plan of Empress Place Building

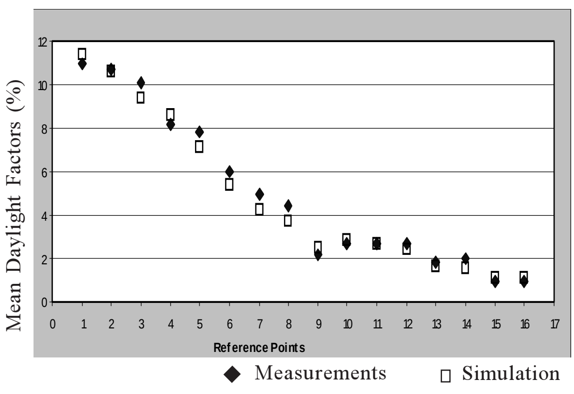

Figure 4 Comparing measured results and simulated results of the Kent Vale test space

PRELIMINARY STUDIES

Radiance has been rigorously validated[7 8 9] and has been successfully used in the design of architectural spaces. As a prelude to the design study, limited test studies were conducted with a simple test cell. The experiment adopts the methodology of Mahdavi[10] and makes use of measured data of the local sky and studies of the local sky models by Lam.[11] The experiment reveals that Radiance performs well in the Tropical climate (figures 4, 5). An average error of 8.1% is recorded between the measured and simulated data. This is in agreement with the 10% error observed by Mahdavi[12], and is better than the 15% observed by Love and Navvab[13] using other simulation software.

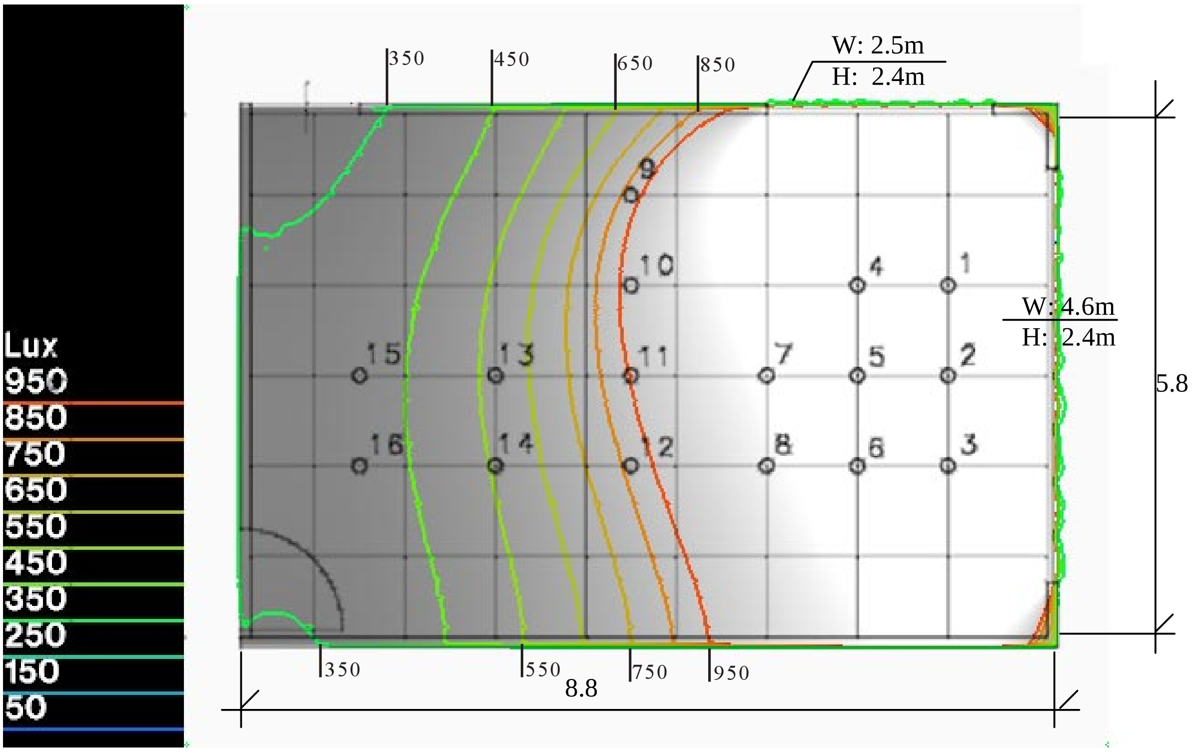

Figure 5 Radiance simulation results of the Kent Vale test space and the location of the 16 reference points

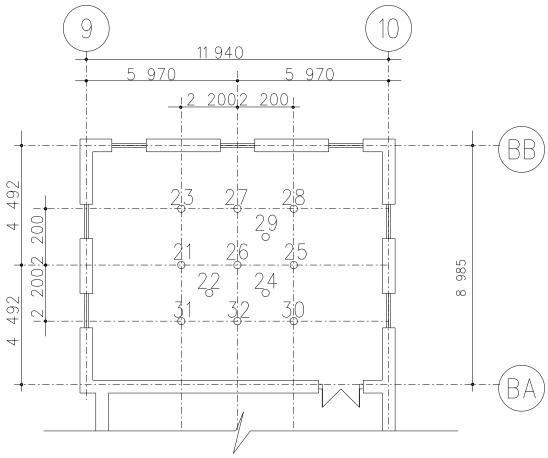

Figure 6 Schematic illustration of the Salon room and the location of the 12 reference points

Figure 7 Interior view of Salon room

MODELLING

The Salon room (measured 12m long, 9m wide and 9m in height) is an annex to the main building located on the second level, which is 5.4m from the ground level. The Room has a total of 14 windows on its east, south and west elevations. Trees immediately outside the building obstruct some of these windows. As the trees are going to stay, the research team was charged with the difficult task to take them into account. This greatly complicates the steps required in the construction the computer model. And it is this area of study that the research team claims most of its original contribution.

Twelve photocells were mounted on the floor of the Room (figures 6, 7), and they were connected to the datalogger and a controlling PC. Two sets of daylight levels were recorded (table 1). Both sets of measurements were conducted under overcast sky conditions. The first set was taken over a period of 2 weeks in October 1997, and the second set in April 1998. The two periods were selected to give a better representation of the year round condition. The maximum, minimum, mean and standard deviation of the points at noon were computed (table 2). It is found that the upper and lower quartiles of the mean are around 20% of the mean.

At the same time, simulations using Radiance were made. To reduce rendering time, the geometric model of the Room was simplified and all minor architectural details

Table 1 Mean values of the illuminance measurements of the measurement points

Measuring Locations	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
Point 21	336	420	418	323	320	304	285	260
Point 22	218	327	316	265	284	268	265	258
Point 23	848	1034	931	663	642	546	513	429
Point 24	187	264	290	264	335	297	337	302
Point 25	180	255	268	298	351	309	365	340
Point 26	147	184	232	216	250	237	242	250
Point 27	305	400	384	323	372	372	334	308
Point 28	213	298	300	318	376	366	405	411
Point 30	226	357	397	391	473	449	491	476
Point 31	722	898	818	542	550	478	431	336
Point 32	296	367	389	301	323	314	331	253

Table 2 Max., Min. and mean illuminance values of the measurement points taken at 12 noon in the Salon room.

Measuring Locations	No. of studies	Max	Min	Standard dev.	Mean
Point 21	10	492	219	76.29	323
Point 22	10	338	180	50.00	265
Point 23	10	1008	461	178.02	663
Point 24	10	357	206	48.65	264
Point 25	10	392	202	64.09	298
Point 26	10	264	114	50.60	216
Point 27	10	457	227	77.09	323
Point 28	10	394	248	56.93	318
Point 29	10	296	169	41.96	246
Point 30	10	466	334	40.18	391
Point 31	10	893	351	155.27	542
Point 32	10	410	201	66.87	301

Table 3 Measured (M) results and Simulated (S) results of the measurement points

Measuring Locations	Type	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
Point 21	M	336	420	418	323	320	304	285	260
	S	542	678	698	548	578	512	498	395
Point 22	M	218	327	316	265	284	268	265	258
	S	231	367	389	332	331	317	284	245
Point 23	M	848	1034	931	663	642	546	513	429
	S	920	1021	1035	832	754	711	534	457
Point 24	M	187	264	290	264	335	297	337	302
	S	246	387	423	430	442	424	412	389
Point 25	M	180	255	268	298	351	309	365	340
	S	356	389	421	550	587	542	567	509
Point 26	M	147	184	232	216	250	237	242	250
	S	246	289	344	348	387	356	345	312
Point 27	M	305	400	384	323	372	372	334	308
	S	512	668	678	698	678	597	565	534
Point 28	M	213	298	300	318	376	366	405	411
	S	623	805	814	841	872	932	913	905
Point 29	M	127	252	239	246	279	266	257	274
	S	289	610	571	524	613	610	584	598
Point 30	M	226	357	397	391	473	449	491	476
	S	234	367	453	478	513	467	472	489
Point 31	M	722	898	818	542	550	478	431	336
	S	655	789	823	512	508	433	398	345
Point 32	M	296	367	389	301	323	314	331	253
	S	215	298	297	312	298	267	254	213

Talbe 4 Correction coefficients

Measuring Points	Correction Coefficient
Point 21	0.60
Point 22	0.89
Point 23	0.92
Point 24	0.72
Point 25	0.60
Point 26	0.67
Point 27	0.57
Point 28	0.39
Point 29	0.44
Point 30	0.96
Point 31	1.09
Point 32	1.18

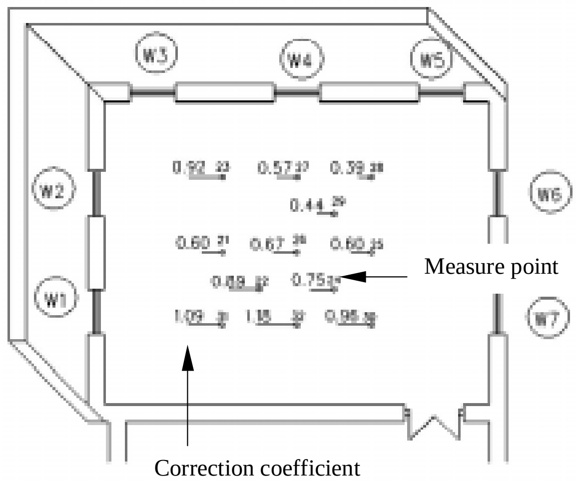

Figure 8 Correction coefficients

were ignored. As it is almost impossible to model the external obstructions, all trees were ignored. The simulated results represented the daylighting conditions of the Room without the external obstruction. The measured and the simulated data are compared (table 3).

To account for the differences in the measured and the simulated data, caused by the external obstructions, correction coefficient of each of the twelve measuring points was calculated using the following minimizing objective function:

$$\min \sum_{i=1}^{9} \left| M_i - CS_i \right|$$

where Mi is the mean of the measurement results
Si is the mean of the simulation results
C is the correction coefficient

The correction coefficients are summarized and presented in table 4 & figure 8. It should be noted that the magnitude of the coefficients largely conforms to the

Table 5 Measured results and ‘corrected’ simulation results of the measurement points

Measuring Locations	Type	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
Point 21	M	336	420	418	323	320	304	285	260
	S	325	250	419	325	345	300	290	237
Point 22	M	218	327	316	265	284	268	265	258
	S	205	324	346	295	291	280	252	220
Point 23	M	848	1034	931	663	642	546	513	429
	S	847	940	970	767	680	640	492	420
Point 24	M	187	264	290	264	335	297	337	302
	S	184	290	317	320	330	318	309	292
Point 25	M	180	255	268	298	351	309	365	340
	S	215	233	250	330	352	324	345	309
Point 26	M	147	184	232	216	250	237	242	250
	S	165	193	230	233	260	238	230	210
Point 27	M	305	400	384	323	372	372	334	308
	S	291	380	450	390	386	340	322	304
Point 28	M	213	298	300	318	376	366	405	411
	S	242	313	320	328	345	363	356	352
Point 29	M	127	252	239	246	279	266	257	274
	S	127	268	254	230	270	269	253	263
Point 30	M	226	357	397	391	473	449	491	476
	S	224	352	434	458	490	448	458	469
Point 31	M	722	898	818	542	550	478	431	336
	S	710	860	850	558	553	471	433	369
Point 32	M	296	367	389	301	323	314	331	253
	S	253	351	350	368	351	315	300	251

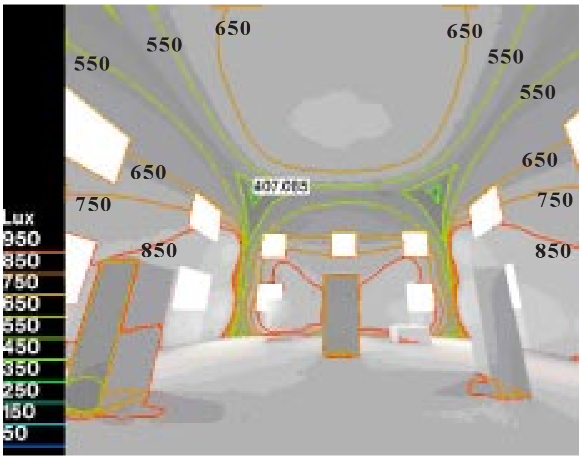

Figure 9 Simulated illuminance distribution in the Salon room with all the windows opened.

research team’s expectation. Larger discrepancies are found at measurements points closer to windows with external obstructions.

Once the correction coefficients were deduced, they were used to re-configure the transmittance settings of the openings used in the calculation of the original simulations. And a new set of simulations was computed. Although mathematical procedures could be developed to determine the contribution of each of the openings to the coefficients, it was found to be unnecessary in practice, as it is quicker to approach it through trial and error. A very reasonable match was achieved after 4 sets of simulation runs (table 5).

At this stage of the research, the team has at their disposal a computer model that behaves close to the real building under overcast sky conditions. This standard model has proved to be invaluable to the design team in examining various options very quickly indeed. To ensure that the turn-around time is fast enough for the design team, a total of 8 SGI were used to compute the simulations. To obtain an overall view of the design options studied, each of the options is rendered with plan, section, perspective and fish-eye views. On average each rendering takes 20-40 hours to render on an SGI 175MHz R10K workstation. A high quality and medium-resolution setting was used in the rad input file.

DESIGN STUDIES

Allowing daylight into an art gallery is a tempting but difficult proposition.[14] The great art galleries and museums of the nineteenth century were all lit with daylight. Recent trend in museum design has also placed great emphasis on utilizing daylight to create small but subtle variations in lighting intensity, to achieve better colour rendition of objects, and to provide visual relief and orientation to the visitors.[15] It has been noted that, in most cases, with the appropriate use of knowledge and information available on how to minimise damage, daylight could be safely used for museums and art galleries.[16] The CIBSE Lighting Guide LG8[17] and IESNA RP-30-96[18] identified a number of key issues for the designers. They are space lighting, display lighting, lighting and conservation.

The Guide touches briefly on lighting and historical buildings.[19] Recognising that most historical buildings were designed to be lit by daylight, the guide identified a number of recommendations. In summary, three are relevant. Firstly, It may sometimes be possible to reduce the transmittance of the window glass. Secondly, all windows should be provided with curtains, blinds or shutters to exclude daylight. And thirdly, the design of shade requires careful consideration and will depend on the particular building.

Table 6 A summary of the 10 design studies.

Part A - Present condition		
Study A-1	With all the windows opened	To study the daylighting performance of the Salon Room without any daylighting control devices.
Study A-2	With high-level windows blocked	
Part B – Options using curtain		
Study B-1	Curtain with 35% transmittance (28.35% diffuse and 3.5% specular)	To study the effects of different transmittance of curtain on the lighting distribution of the Salon room.
Study B-2	Curtain with 60% transmittance (48.60% diffuse and 6.0% specular)	
Part C – Options using louvers		
Study C-1	Horizontal louvers with 20% reflectance.	To study the effects of reflectance and angles of varies louvers systems on the lighting distribution of the Salon Room. The width of each louver slat is 50mm and the distance between the slats is 50mm.
Study C-2	Horizontal louvers with 50% reflectance	
Study C-3	Horizontal louvers with 80% reflectance	
Study C-4	45-degree slant lovers with 20% reflectance	
Study C-5	45-degree slant lovers with 50% reflectance	
Study C-6	45-degree slant lovers with 80% reflectance	

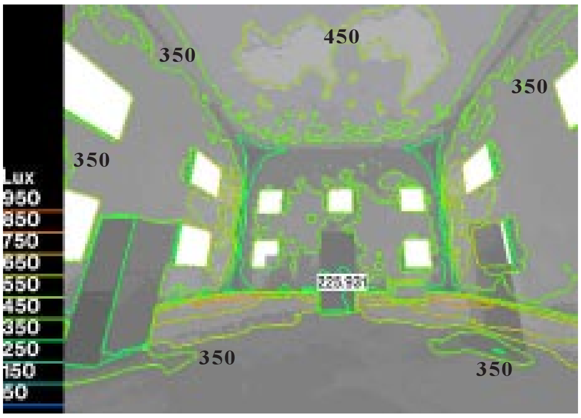

Figure 10 Simulated illuminance distribution using blinds with a 35% diffuse transmittance.

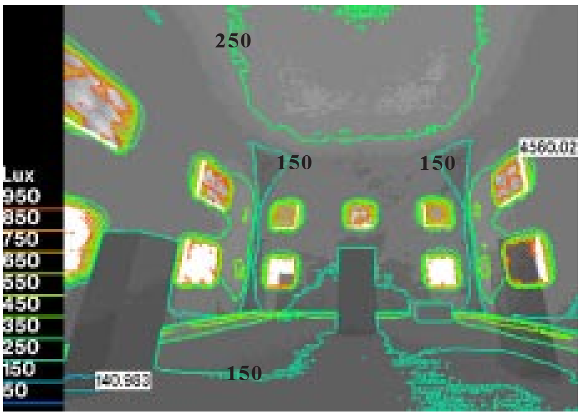

Figure 11 Simulated illuminance distribution with 45 degree slant louvers of 50% reflectance.

To determine the extent of the problem, simulations were carried out for the Room with all windows opened and without any form of daylight control devices. Daylight levels in excess of 1000lux were observed (figure 9).

Two design constraints were imposed by the curator and the architect. Firstly, the window glass itself has to be clear. This rules out using any form of tinted glass to reduce transmittance. Secondly, for historical correctness, a certain style of louvers has to be installed. But they could be kept in an open position if necessary. Dynamic louvers system was ruled out because of cost, maintenance and aesthetic reasons. The two design objectives requested of the research team were to examine the use of curtain blinds and louvers:

To reduce daylight levels of the Room to an acceptable level (around 150 Lux on the main surfaces of the space, and as directed by the conservation specialists).

To attempt to correct the inherent deficiencies of side-lit spaces and to redistribute daylight more evenly over and in particular towards the ceiling of the space.

Ten options were studied (table 6). Studies B-1 and B-2 involve blind materials, and studies C-1 to C-5 involve venetian blinds. The modelling of the blind materials and venetian blinds followed recommendations by Gregory Ward, author of Radiance.[20 21]

When curtains are used, it was found that curtains with a transmittance of 35% or less should be installed to reduce daylight levels to an acceptable limit (figure 10). A few 'hot-spots' around the perimeter of the space were observed.

When Louvers are used, it was found that 45 degree slant louvers with a surface reflectance of 0.5 yielded the most satisfactory results (figure 11). In addition, it was found that louvers were more effective in redirected light towards the top parts of the Room, eliminated the hot spots, and made the Room appeared to be brighter. It was also observed that alternating the angles of the louvers had a high impact towards the daylight levels and their distribution than changing the reflectance of the surfaces.

CONCLUSION

The research highlighted some of the difficulties of modeling and simulation under a real life context and offered a work around method to overcome the problem. The method introduced here is only suitable for the design of existing buildings where measured data could be obtained and correction coefficients could be calculated.

The research project from the validation stage to the design stage lasted eight months. This largely coincided with the progress made by the architect design team. There had been periods of rush towards the end when large number of simulations had to be produced over a short period of time. However, on the whole the scheduling was comfortable. It should be noted that similar undertaking could be accelerated in future as it is no longer necessary to validate Radiance.

The solution finally adopted was using 45 degree slant louvers with a surface reflectance of 0.5. The surface reflectance is achieved by painting a semi-gross off-grey colour to the louvers. Incidentally, the section finally adopted is very similar in profile to louvers commonly used in the region - proofing that there is indeed such a thing as traditional wisdom.

Daylighting is not an exact science. From the measured data, a fluctuation of 20% is expected. And an error of 8% is also recorded in the simulations. Thus, the use of blinds as a secondly defense has not been ruled out entirely. However, they could be retrofit very easily towards the end of the construction process.

FURTHER STUDIES

The research work is ongoing. Higher resolution and more realistic rendered images have been produced (figure 12). They give the client some feels of the visual quality of the interior spaces. Additional studies involving other sky conditions are also proposed. This will be preceded with a study on environmental factors like cloud cover.

The research team attempts to verify the simulated data when the building is finally completed in year 2000. This will provide a solid grounding to the use of Radiance and the simulation model in any future alteration of the Room. The rest of the museum spaces could also be simulated. As the simulated model could be used to provide detailed information of any surfaces located in the architectural space, it could be used to aid the design of exhibition layout. This will enable the curator the freedom to maximize the available daylight by placing less light sensitive exhibits in areas where greater amount of daylight is expected. It can also be used to determine the needs for and the design of additional artificial lighting.

Figure12 An example of a high resolution rendered view of the Salom room

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FURTHER INFORMATION

Dr Edward Ng
Department of Architecture,
The Chinese University of Hong Kong,
Shatin, NT, Hong Kong
Email: akienyy@yahoo.com

A full report of the research project titled Advanced Lighting Visualisation in Architectural Design (RP960019) could be found at the

Information Resources Centre,
Faculty of Architecture, Building and Real Estate,
National University of Singapore
47 Architecture Drive, Singapore 117592.